An Engineering Funds of Knowledge Framework

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Introduction

Layla created a 3-dimensional, light-up paper lantern-style mug as a gift for her mother during an engineering unit focused on energy systems (Photo 1). To light her mug, Layla designed and built a parallel circuit using 2 LED lights, copper tape and a coin cell battery. The switch, a movable flap between the battery and copper tape, was decorated with a bow.

Layla drew upon many personal and cultural resources, including her passion for making and crafting. She explored pictures of 3-dimensional lanterns and cards on Google Images and drew from her prior positive experiences making 3-dimensional and tech-centric projects like a working robot with her brother. In addition to drawing on resources to successfully engineer circuits in a 3-dimensional way, the electric art templates provided in the engineering unit informed her circuit design. Decorations to increase "coziness" were carefully added, including gluing flowers on the mug's base so "it can look like it's just wonderful imaginary world of yours" and a curling pipe cleaner to represent a steaming beverage. Her initial design with only one LED was not "cozy" enough. So even though "it took a long time to do the circuit" she added a second light, requiring her to switch from a simple to parallel circuit.

Layla felt proud as she shared, "I feel like I can teach, and if someone asks me about LED lights, series circuits, simple circuits or parallel circuits, I can help them." She predicted that her mom would "think that I am very creative, very smart, and very thoughtful that I did this for her. And she's going to think I'm successful."

Photo 1. Layla's 3-dimensional, light-up, paper lantern-style mug

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An Engineering Funds of Knowledge Framework

Layla's experience illustrates how having opportunities to leverage her various *Funds of knowledge* (*FoK*) while making a light-up mug helped her engage deeply in STEM knowledge and practices, leading to feelings of accomplishment. FoK are the various forms of expertise and practices youth develop over time in families and communities, and that can be strategically leveraged for learning and participation in school settings (Llopart & Esteban-Guitart, 2018). Family and community (e.g., parents' work in and outside the home, travel, and environmental and health concerns); peers (e.g., formal and informal group activities); and popular culture (e.g., TV, music, print and social media) are some categories of FoK (Calabrese Barton & Tan, 2009). Supporting students in using their FoK in engineering is an asset-based approach to supporting STEM learning, and provides opportunities to connect school and community. By community, we refer to the people and places that students interact with on a regular basis.

When FoK are strategically tapped into, students have opportunities to engage with knowledge that is familiar to them, as a foundation for more sophisticated content-based learning (Authors, 2017; Civil, 2018). Layla's mug highlights this point. Layla's FoK developed with her brother making three-dimensional objects, crafting at home, using technology to support her craft and technical efforts as well as learning circuits in school, supported her engagement in the electric art project and optimizing it.

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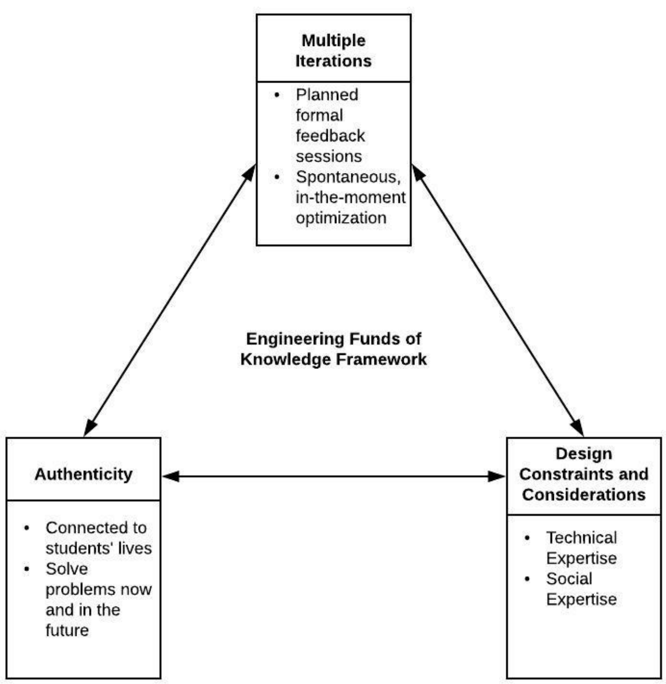
It is well established that drawing upon students' FoK supports powerful learning outcomes, especially for youth whose life experiences are not always valued in dominant classroom spaces. Yet, teachers can struggle to find ways to do so (Gonzalez, Moll & Amanti, 2005). In this article, we introduce an *engineering FoK framework* to better support teachers in positioning students to leverage their FoK in engineering. The framework focus on three aspects of engineering design challenges. Design challenges should 1) require both technical and social expertise, 2) support multiple design iterations within the design challenge and 3) connect authentically to students' lives. Table 1 shows how the engineering FoK framework principles are connected. Below we highlight these three principles through guiding questions and explanations to support teachers in planning and in-the-moment strategies that leverage students' FoK in engineering.

Figure 1. The engineering funds of knowledge framework



How can an engineering challenge support students in developing and using technical and social expertise?

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Engineering design challenges should support students' leveraging of multiple funds of knowledge. The first key framework principle is that design constraints should require both technical and social expertise. Technical expertise is often grounded in STEM knowledge, while social expertise can be built from drawing on students' multiple FoK. Such a dual focus can support students in developing *new forms of expertise* that *combine* STEM knowledge with FoK. This makes developing one's expertise in science more authentic and motivating. Within the FoK engineering framework, it is important for students to be able to use and further develop multiple types of FoK, related (but not limited) to STEM expertise and family/community expertise.

To plan ahead, teachers should consider what expertise students might be able to tap into because of who they are and where they have grown up that could be useful in an engineering design challenge. During class interactions, teachers can challenge students to address technical *and* social aspects of the design challenge and their solution. Additionally, they can recognize and encourage students to use multiple resources to develop and leverage the different forms of expertise that they need to complete the engineering design challenge. During the design process, teachers can observe how students use multiple funds of knowledge in their engineering design work. After students complete the engineering projects, teachers can ask students what different types of knowledge helped them be successful in the design task. Mrs. L used an interview rubric to elicit students' thinking.

Layla's FoK included her expertise in crafting and robotics, developed at home with her mom and brother. Layla brought in her artistic talent, internet searching expertise, love of robotics, and desire to make a gift for her mother to engage deeply in learning about energy transformations and hands-on engineering design. Layla combined her developing knowledge

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and practices in science with her expertise on what might make a light-up mug cozy. Layla brought her multiple expertise into the design challenge that emphasized incorporating a working circuit into art to make a gift for a loved one. If Layla's teacher, Mrs. L, only emphasized the science expertise required, she would not have been supported in using such a wide range of expertise. Mrs. L, through an informal interview, asked Layla what expertise she used to make her card and by looking at the card she also could see multiple forms of expertise used. Creating space for all of these forms of expertise through a design challenge that required both technical and social expertise was important to both her success and motivation.

How does the design challenge leverage upon funds of knowledge to support multiple iterations?

Through engaging students in multiple design iterations, teachers create sustained opportunities for students to deepen STEM understanding while integrating students' care for and knowledge about loved ones**.** Through multiple design iterations, students have opportunities to bring new expertise into their engineering learning. During these design iterations, teachers foster opportunities for students to share their FoK with others, leading to increased recognition of student expertise as well as supporting design optimization. This helps students to see themselves as capable and confident in science while expanding and strengthening their own engineering expertise. To ensure that students are moving through multiple design iterations, teachers should ask students what changes they have made and why, to their engineering designs throughout the engineering cycle.

Teachers can schedule formal feedback sessions with the class and larger community at multiple points throughout the unit. Additionally, they can scaffold iterations into the design challenge (e.g., Formal iteration 1: Paper circuit template; Formal iteration 2: Electric art for a

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loved one). In-the-moment strategies such as encouraging students to immediately ask for feedback from their peers or others that will be impacted by their engineering design solutions, will support flexibility in the engineering design cycle. This flexibility will allow for students to engage in multiple engineering design iterations throughout an engineering challenge.

Layla went through many iterations before having a working 3-dimensional light-up mug. Each iteration was prompted by challenges that advanced her sense-making. When she thought her mug needed to be more "cozy" she added a second LED light, prompting further circuitry explorations, plus additional crafting features, such as the curling pipe cleaner to represent the steaming hot beverage. These iterations invited Layla to use multiple types of FoK. To evaluate Layla's various design iterations, Mrs. L asked her to explain the process she undertook making the electric art and then asked her how each change she made deepened her expertise using the post-electric art interview rubric.

How does the engineering design challenge authentically connect to students' lives?

Engineering design challenges focused on solving local, real-life challenges support students in using multiple FoK. Engineering designs that continue to be used within the community provide continued recognition and legitimization of students' wide-ranging expertise. Teachers planning authentic design challenges should ask where, when and how the engineering design solutions can be used by the students and/or their community.

When planning an authentic design challenge, teachers should ask how they could connect disciplinary core ideas and engineering practices to local issues. Asking students for ideas can help with this brainstorming and teachers should encourage students to optimize their designs for ease of use and durability. If the engineering designs stay in the classroom, teachers

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should ensure that they are regularly used. This recognizes students' multiple FoK and shows that their engineering work matters.

Consider how the electric art challenge was authentic. Layla was able to create something that mattered to her mom and her. The light-up mug was used for a long-time after the energy engineering unit was over. Mrs. L was able to evaluate if the design challenge authentically connected to Layla's life when she saw that the card lit up and read Layla's response to this question, "Why do you think they (the recipient of your card) will like your electric art?". This recognized Layla's multiple FoK and legitimized her engineering efforts.

Relationship between the Three Guiding Principles

The three principles of the engineering funds of knowledge framework (design challenges that require technical and social expertise, multiple iterations, and are authentic) build on and support each other. An authentic design task requires students to develop and use social and technical expertise and engage in multiple iterations to complete the design task in ways that matter beyond learning STEM knowledge. When engaging in pedagogical planning, teachers should consider these guiding principles as integrated rather than separate. See Table 2 for planning and in-the-moment strategies to enact this framework.

Applying the Engineering Funds of Knowledge Framework to an Engineering Design Challenge

We highlight the engineering FoK framework through an electric art engineering design challenge because it is popular and used across multiple grade levels (3^{rd}-6^{th}). However, the framework is applicable to any engineering unit. The electric art design challenge is meant to support students' sense-making of a) core disciplinary ideas on energy systems (e.g., power

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requirements) and transformations (e.g., electrical to light energy) and the two engineering practices, defining a problem and designing a solution. Rather than only asking students to make and test different circuit types and draw model-based explanations for how and why the circuit types work, students leverage these insights towards making a light-up gift for a loved one, limited to the following materials: one 3-volt battery, up to two 5mm led lights, copper tape, cardstock and other common classroom craft supplies. While this electric art design challenge is not new, the ways in which the teacher used the framework to support her students in leveraging their FoK, while delving deeply into the engineering, highlights the transformative outcomes of this approach. Templates, supply information and student hand-outs are available for download for this lesson.

The engineering FoK framework guided two iterative, electric art design cycles. Students decided who they were making their electric art for and how to design it both socially (artistically) and technically (circuit-wise) to celebrate that person. They accomplished this through two cycles of prototyping. In the first cycle, students modeled three types of circuits (simple, parallel and series), analyzing and developing evidenced-based explanations for the different advantages and constraints of each circuit type regarding power requirements. This is often where circuitry and energy lessons stop.

The students then used this expertise in a way that mattered to them as they designed their own electric art. During this second prototyping cycle, students leveraged personal, family and community resources, in personalizing their electric art. Students were positioned as experts as they helped peers make their cards. Their hybrid-expertise involved helping peers trouble shoot how to make their circuits and switches work within their desired social specifications of their designs, or to modify their specifications as they moved through multiple iterations. The

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teacher encouraged peer-help and used student-made cards as resources for struggling groups. When the students delivered their electric art cards to loved ones, they were further positioned as experts as they often explained how circuits worked. Teachers can assess if their implementation of the electric art lessons and other units supported students in deepening their expertise by asking informal questions across the design challenge, observing the students' actual engineering design and interviewing students. This multi-prong assessment approach can help teachers see if and how they supported students in incorporating their multiple funds of knowledge in the engineering process.

Below we explore how our framework supported students in using their FoK and supported transformative outcomes.

Vignette: Sage - Learning to see herself as a science person

> "It says I am determined. I can push through, and that I care about people. I am creative and smart." -Sage describing what the electric art card

Sage describes herself as a "young, smart girl, who likes to be creative. I'm sweet and I just want the best for everyone." Everyone who knows Sage agrees. This exceptional care for others was shown in her electric art card for her mother designed to say "I love you," embellished with a single light in the "o" of "love".

When she started creating the circuit, Sage realized her mother only spoke and read in Arabic. She decided to write "I love you" in Arabic, a design iteration to make the card more meaningful to her mother.

Sage utilized multiple resources in the process. While Sage speaks Arabic at home, she has not yet learned to read or write Arabic, leading her to use Google Translate to look up how to write "I love you" in Arabic. With the language change, Sage had to change her design (the light

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could no longer go in the “o” in “love”). She also decided to “hide” the circuit on the inside of the card so that she had space to draw a rose.

Photos 2 and 3. Sage’s pop-up simple series “I love you” card for her mother

Through the utilization of FoK and design iterations, Sage developed robust expertise. Sage utilized her knowledge from the electric art lesson, her understanding of her family, and access to technological resources. These factors played into Sage’s learning, making the design challenge more meaningful and memorable. Furthermore, it allowed Sage the opportunity to share her new expertise as she showed love to her mom, explain to her family how the circuit work, and then had her card displayed in her home.

Table 1. Examples of the engineering funds of knowledge framework in practice

Student	Electric Art	How can an engineering challenge support students in developing and using technical and social expertise?	How does the design challenge leverage upon funds of knowledge to support multiple iterations?	How does the engineering design challenge authentically connect to students’ lives?
Layla	3-d Light Up Mug	Used knowledge developed in her relationships with Mom and brother	Changed from 1 light (simple) to 2 lights (parallel)	Designed a mug for her mom that was 3-D, imaginative and

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		Love for 3-d and robotics Big DIY-er Loves Art projects Savvy Internet Browser	Added lots of decorations to make the mug cozier Added pipe cleaner to represent steam Kept working on it after class finished lesson Helped others make switches and circuits after getting help with her own switch Offered feedback to others on their art	glittery, light-up that built on previous experiences making paper lanterns
Sage	Light up card "I love you" in Arabic	Knowledge and love of her mom Arabic language Used Google Translate to write "I love you" in Arabic	Had to reorganize her circuit because she changed the language. Decided on a switch that she didn't think would take away from the middle Teacher helped her create the pop up aspect of her design	Created an electric art card for her mom that conveyed her love and communicated with her in her preferred language Recognized by her whole family as she taught how them how her card worked and then it was displayed prominently in her house
Leo	Waterproof Koala Bear Card	Knew his brother drooled a lot, knew duct tape was waterproof, knew how to create a baby-themed koala bear inspired by his little brother's	Had to go back and waterproof the card with duct tape, colored the white light red so it would look like a heart and better represent	Was able to give a gift to his brother, which he wanted to, but was unable to do previously at his brother's baby shower

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		stuffed animals and bear-shaped honey containers his family bought	his love for his brother, labeled the positive and negative leads of the light bulb to support him in making a working circuit when he initially could not get it to work	

Why supporting students in leveraging their funds of knowledge matters?

Designing engineering challenges that support students in leveraging their FoK support equity-oriented outcomes that teachers may never expect. Consider Leo who created a light-up koala bear for his baby brother. He was inspired by his brother's stuffed animals and his family's bear-shaped honey containers. He went through multiple design iterations as he worked to make a working circuit that was waterproof because his younger brother drools a lot. He colored the light bulb red to make it look like a heart, and he wanted the heart to represent his love for his brother. Leo used this engineering challenge as a chance to make something meaningful for his brother, as he had no gift for him at his baby shower. Developing and using their FoK supported Leo, Sage and Layla **as well as over 450 other students we have worked with in successfully making electric art,** in deeply engaging in the engineering practices, learning new electricity expertise and doing something that mattered to their community and themselves.

Photo 4. Leo's waterproof, light-up heart koala bear card to celebrate his baby brother

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The **e**ngineering FoK framework can be applied to any engineering unit. We offer strategies that can help classroom teachers to support students in using their FoK in all engineering units. (See Table 2.) Utilizing this framework may support more students in having **valuable learning experiences like Layla, Sage and Leo did.**

Table 2. Strategies to enact the funds of knowledge framework

	Question	Big Idea Explained	Planning Practices	In-the-Moment Practices
Design Constraints and Considerations	How can an engineering challenge support students in developing and using technical and social expertise?	Engineering design challenges should support students in developing both technical and social expertise. In doing so students will be supported in integrating multiple types of funds of knowledge into their engineering work.	• Make sure the engineering designs require both technical and social expertise • Design scaffolds to support students in considering the technical/social dimensions of engineering	• Ask students about the technical and social aspects of their design solution • Publicly recognize students' STEM and other forms of expertise as important and necessary for their groups' efforts

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			problems and solutions	
Multiple Iterations	How does the design challenge leverage upon funds of knowledge to support multiple iterations?	As student engage in multiple design iterations, students have opportunities to bring new expertise into their engineering learning. This is supported by interactions with peer and teachers as well as using and developing other funds of knowledge, like technological, social media and family practices.	• Plan formal feedback sessions with the class and larger community • Plan scaffolded iterations into the design challenge (ex. Formal iteration 1: paper circuit template; formal iteration 2: electric art for a loved one)	• Encourage students to ask for feedback from people who will be most impacted by their engineering design • Support students in leveraging each others expertise through peer-to-peer interactions • Encourage students to use youth-centered resources not always valued in classroom spaces that will help with the design process (ex. Social media sources, collaborative interactions with peers)
Authentic	How does the engineering design challenge authentically connect to students' lives?	Engineering design challenges focused on solving local, real-life challenges support students in using multiple funds of knowledge. Additionally, engineering designs that	• Center the design challenge on a local issue • Plan opportunities to share their work throughout and after the engineering design challenge	• Encourage students to optimize their designs so they are more likely to be used due to ease and durability • Use the engineering designs

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		continue to be used within the community after engineering unit will provide recognition and legitimize students' multiple forms of expertise that they used making their design	• Engineering designs should be able to be used within the community	

Table 3. Connecting to the *Next Generation Science Standards* (NGSS Lead States 2013)

Standard *3-5-ETS1-1* The chart below makes one set of connections between the instruction outlined in this article and the *NGSS*. Other valid connections are likely; however, space restrictions prevent us from listing all possibilities. The materials, lessons, and activities outlined in the article are just one step toward reaching the performance expectation listed below.	
Performance Expectation	Connections to Classroom Activity *Students:*
Define a simple design problem reflecting a need or a want that includes specified criteria for success and constraints on materials, time, or cost.	• Chose the recipient of their electric art • Defined the technical and social criteria for a successful electric art design
Science and Engineering Practice	
Asking Questions and Defining Problems Constructing Explanations and Designing Solutions Obtaining, Evaluating, and Communicating Information	• Defined the criteria of a successful electric art card • Designed an electric art card responding to technical and social constraints • Explained how to make working circuits to fellow students and loved ones
Disciplinary Core Idea	
ETS1.A: Defining and Delimiting Engineering Problems	• Decided what made their electric art card a success based on community and technical expertise

PS3.A: Energy can be moved from place to place by moving objects or through sound, light, or electric currents. (4-PS3-2),(4-PS3-3) PS3.B: Energy can also be transferred from place to place by electric currents, which can then be used locally to produce motion, sound, heat, or light. The currents may have been produced to begin with by transforming the energy of motion into electrical energy. PS3.D The expression "produce energy" typically refers to the conversion of stored energy into a desired form for practical use.	• Designed working circuits • Analyzed the constraints and benefits of different circuits • Sketched and built circuits that allowed for an effective transfer of energy
Crosscutting Concept	
Energy and Matter: Energy can be transferred in various ways and between objects.	• Analyzed multiple forms and transfers of energy (Chemical potential energy, electricity, light energy)

Connections to the *Common Core State Standards* (NGAC and CCSSO 2010):

ELA	**RI.5.7** - Draw on information from multiple print or digital sources, demonstrating the ability to locate an answer to a question quickly or to solve a problem efficiently. **W.5.8** - Recall relevant information from experiences or gather relevant information from print and digital sources; summarize or paraphrase information in notes and finished work, and provide a list of sources.
Mathematics	**MP.5** - Use appropriate tools strategically.

Safety Information

This activity is ideal for 3rd to 6th grade students. Students should use scissors to cut copper tape to avoid copper tape cuts. The batteries should be kept away from young children who may put them in their mouth.

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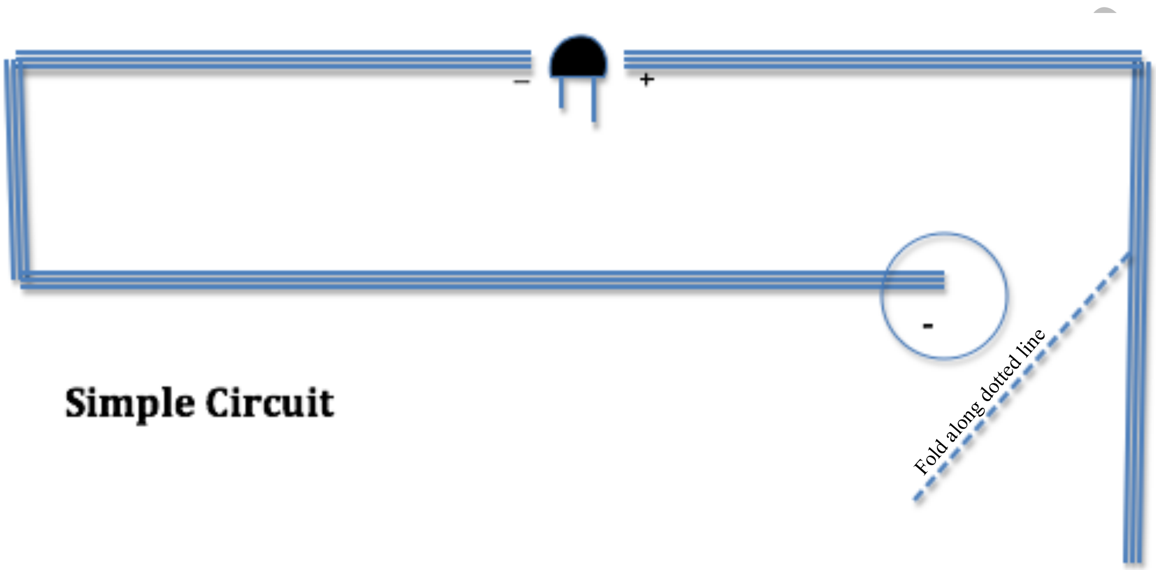
Downloadable material:

Group Members ____________________ Electric Art- Iteration 1



Simple Circuit

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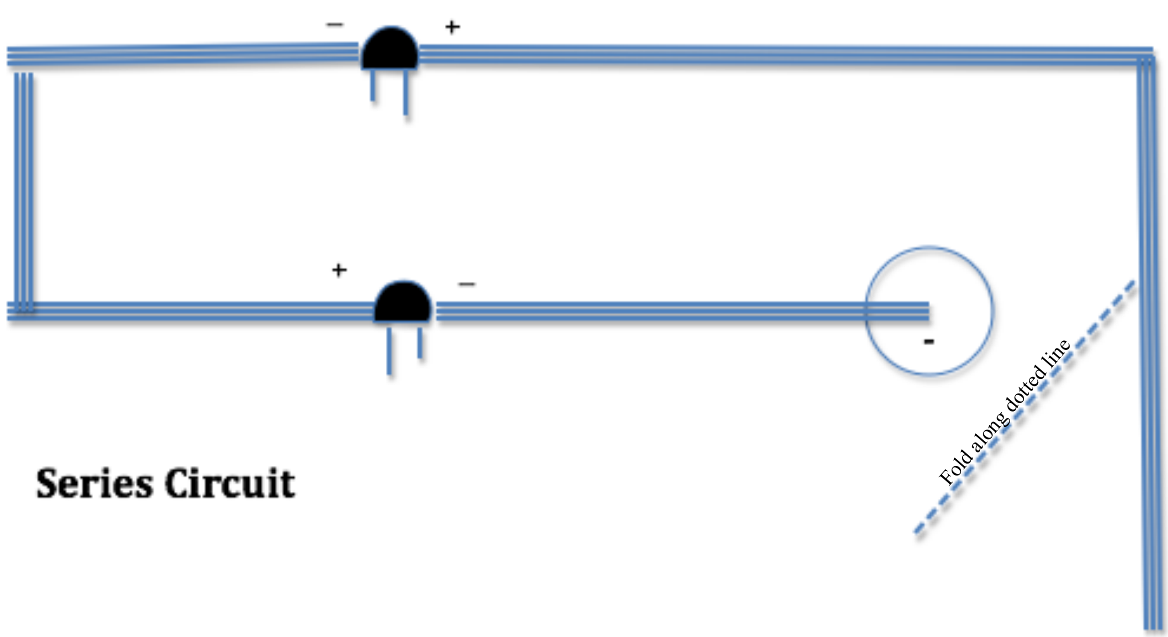
Group Members ______________________ Electric Art- Iteration 1

Directions:

- Did your 2 lights light up? ______________
- Were they as bright as in a simple circuit? If not, how could you make them bright? ______________
- Show the flow of electricity with an arrow and label on the template.
- Label the components of the circuit: power source, load, switch, and pathway.



Series Circuit

Group Members ______________________ Electric Art- Iteration 1

Directions:

- Did your 2 lights light up? ______________
- Were they as bright as in a simple circuit? If not, how could you make them bright? ______________
- Show the flow of electricity with an arrow and label on the template.
- Label the components of the circuit: power source, load, switch, and pathway.

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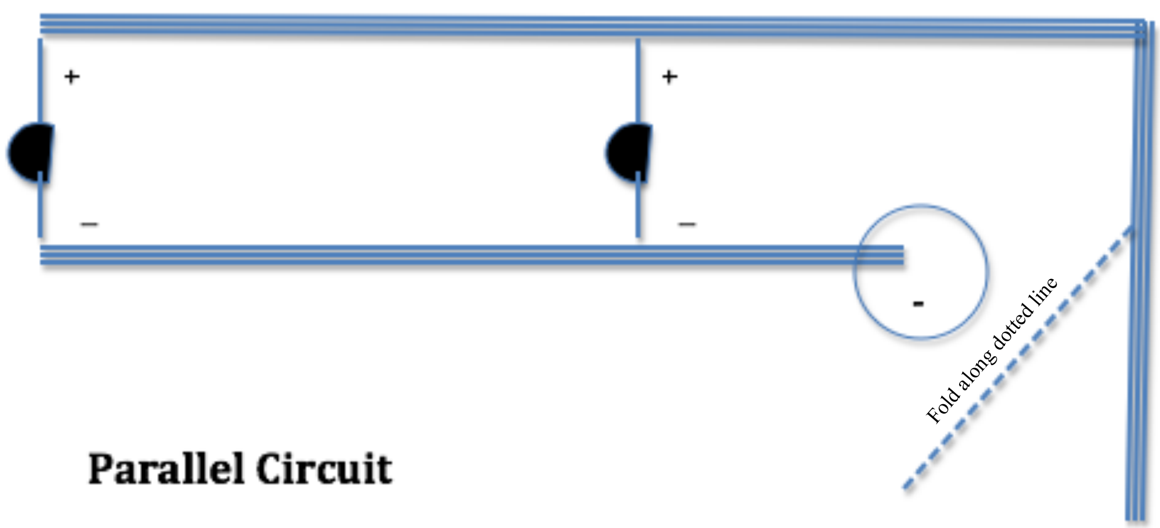

Parallel Circuit

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Name_______________________________ Electric Art- Iteration 2

Check List:

My design uses:

- A battery ______
- A LED light bulb ______
- Copper tape ______
- Has a switch ______

1. Draw and label your electric art circuit.
2. Label: Copper tape, LED light, battery, switch, current flow (use arrows).

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How does your design work? (Make sure to discuss the energy transformations)

Who is going to receive your electric art?

Why do you think they will like your electric art?

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Grouping Information:

For electric art iteration 1 (electric art templates): have students work in groups of 3 so each student can complete one electric art template (simple, series and parallel)

For electric art iteration 2 (making electric art cards): have each student work on their own project, but encourage them to help each other with both the technical and social dimensions of their design.

Supply Information:

	How much:	Where to buy:
Copper Foil Tape with Conductive Adhesive - 6mm x 15 meter roll	3 rolls per class of 30 students	https://www.adafruit.com/product/1128
Cardstock	1 piece per student	Craft stores, school supply stores, online
10 MM LED light bulbs	2 light bulbs per student	https://www.adafruit.com/product/846
CR2032 3v Lithium Coin Batteries	1 battery per student	You can buy these in stores, but also in bulk from Amazon.com. They can only be shipped via ground transportation so order ahead of time.
Classroom craft supplies and equipment (scissors, tape, markers, crayons, etc..) *Have students re-use the light bulbs and batteries from electric art iteration 1 in their electric art iteration 2 to conserve materials.		

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Post-Electric Art Interview Questions and Rubric

Ask students these questions to be able to complete the feedback rubric:

1. For whom, did you make your electric art card?
2. What do you think they will like about it?
3. Will you please explain and show me how it works?
4. What was your process for figuring out how to make the electric art card?

*Teachers can ask each students these questions or students can interview each other and fill out their own self-evaluation rubric.

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Big Ideas		Criteria	Is this present?			Feedback:
			No Evidence	Evidence Present	Strong Evidence	
Engineering for Sustainable Community Principles	Uses community members' ideas in engineering	Modified design based on classmate, community member and teacher feedback				
		Tailored the social and technical aspects of the card for its intended purpose (Made the card in a way they knew the person they were giving it to would like it.)				
Energy Practices	Designing Solutions	Utilized social design aspects to help solve problem				
		Designed a working circuit				
Energy Content knowledge	Types of Energy	Explained that the battery was the source of energy				
	Energy Flow	Labeled the components of a circuit (switch, pathway, light or load, battery)				
	Energy Transformation	Explained/labeled the direction of electricity flow through the parallel or series circuit				
		Explained how energy was transferred in the circuit				